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Facility for the Evaluation of Space Communications and Related Systems

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ABSTRACT

NASA Lewis Research Center's Communications Projects Branch has developed a facility for the evaluation of space communications systems and related types of systems, called the Advanced Space Communications (ASC) Laboratory. The ASC Lab includes instrumentation, testbed hardware, and experiment control and monitor software for the evaluation of components, subsystems, systems, and networks. The ASC Lab has capabilities to perform radiofrequency (RF), microwave, and millimeter-wave characterizations as well as measurements using low, medium, or high data rate digital signals. In addition to laboratory measurements, the ASC Lab also includes integrated satellite ground terminals allowing experimentation and measurements accessing operational satellites through real space links.

INTRODUCTION

The space communications program at NASA's Lewis Research Center is focused on the development of advanced technologies for future space communications systems. The results of the program are often manifested in proof-of-concept components and subsystems as well as new system and network concepts. Examples include receivers and transmitters, low and high data rate digital subsystems, advanced digital modems, integrated ground terminal subsystems, a satellite-based space science data distribution network design, and the experimental Advanced Communications Technology Satellite (ACTS).

Characterization and evaluation of components and validation of system concepts is required, both for verifying contractor performance and for determining the readiness and suitability of new technologies. NASA Lewis's approach to evaluation uses both standard unmodulated signal measurements and modulated data transmission measurements, and includes both laboratory and space-link testbed facilities. These measurement capabilities are integrated into the Advanced Space Communications Laboratory at NASA Lewis.

TECHNOLOGY EVALUATION REQUIREMENTS

There are five categories of evaluation requirements for space communications technology: 1) Radiofrequency (RF) component/subsystem stand-alone unmodulated signal testing, 2) RF and digital component/subsystem modulated signal testing, 3) unmodulated and modulated testing of systems, 4) system and network functional testing, and 5) system level experiments and application demonstrations.

RF Component and Subsystem Stand-alone Unmodulated Signal Testing

Most RF components and subsystems which are developed for proof-of-concept or operational purposes require a battery of tests using unmodulated signals to determine their performance to specification and the amount of signal degradation they will contribute when used in an end-to-end communication system. The most important types of tests performed are gain, phase, noise figure, and group delay as a function of frequency, signal non-linearity, phase noise, and frequency stability. These parameters sometimes are measured as a function of temperature; however, the ASC Lab does not have full thermal-vac facilities.

RF and Digital Component and Subsystem Modulated Signal Testing

Many of the RF components and subsystems described above, as well as all digital and modulated signal components and subsystems, must be tested using modulated signals. The signals are usually digitally modulated, but analog forms of modulation (such as FM video) are also used. These tests evaluate the performance of the component or subsystem in terms of its ability to process an appropriate modulated test signal. The results are expressed in terms of bit-error rate (BER) for a digitally modulated signal, or signal quality (signal-to-noise (SNR), distortion, or subjective picture quality), for an analog modulation.

System Level Unmodulated and Modulated Signal Testing

The performance of an end-to-end system must be evaluated in terms of both unmodulated and modulated signal parameters. In most cases, the systems under consideration at NASA Lewis are digitally modulated space communication links, i.e., from a ground source through an orbiting satellite to another ground destination. Other cases include space to ground links, such as a low-earth orbit scientific or earth observation satellite transmitting data to a ground station, intersatellite links, and terrestrial microwave links. The unmodulated signal measurements required are the same as those mentioned above. The modulated signal characteristic required for a digital communication system is the BER, measured as a function of energy-per-bit to noise power density ratio (E_b/N_o), frequency, transmitter power level, or other parameters depending on the design of the system. For analog modulated systems, it is the output SNR or subjective picture quality as a function of these various parameters which is the desired result.

System and Network Functional Evaluation

A system, consisting of perhaps a single satellite link, and a network, consisting of several interconnected systems or portions of systems, require functional testing. This testing determines such things as network setup times (e.g., the acquisition time for a ground terminal to enter the network), system efficiency and capacity, overall performance quality, and ability to accommodate or counteract expected and unexpected system disturbances. This requires simulated users to stimulate the network, a capability to simulate

system disturbances, and a computer-based control and monitor capability to measure and assess the various system and network performance parameters.

System Level Experiments and Application Demonstrations

In the evaluation of new technologies, system level experiments are carried out to determine the potential performance under real operating conditions. Demonstrations of possible applications are then necessary to foster utilization of the new technology. System level experiments generally consist of system operations performed in the presence of impairments or disturbances, such as signal interference, rain attenuation, or degraded component or subsystem performance. They can also consist of comparisons of system performance under varying parameters, such as transmitter power level, number of simultaneous channels, or different modulation or coding schemes. The results of such experiments are end-to-end BER's, SNR's or subjective picture quality, sometimes as a function of other system parameters.

In order to evaluate applicability and foster use of newly developed technologies, realistic demonstrations of potential applications are carried out. Satellite communications applications include high definition television (HDTV) transmission, video and image compression, low and high rate data transfers, remote interconnectivity and interfacing between terrestrial and space-based systems, and telemedicine.

System experiments and application demonstrations can be carried out using a laboratory based testbed as well as a real operating system. The laboratory based model has many advantages. System parameters can be easily varied, hardware is readily reconfigurable, and many variations can be attempted without expensive development, buildup and deployment of operational or "flight qualified" hardware. The real operating system, when available (for example, in an experimental system such as ACTS) provides the most acceptable level of demonstration, involves actual system impairments and variations (as opposed to laboratory simulations), and can also connect geographically remote experimenters and potential users. The ASC Lab facilities include both laboratory based testbeds and a real operating system testbed.

INTEGRATED FACILITY FOR TECHNOLOGY EVALUATION

The ASC Laboratory at NASA Lewis is an integrated facility consisting of RF test systems, a laboratory-based Space Communications System Simulator and Testbed (System Testbed), and a Space Link Testbed. An experiment control and monitor system operates the System Testbed and links it with two operational ground terminals to create the space link testbed.

RF Testing

RF testing consists of tests using unmodulated continuous wave (CW) signals. Some RF measurements, such as power and frequency, can be integrated into the satellite system or space link testbeds. The more complex RF measurements require computer integration and control for efficiency, accuracy, and repeatability. In order to apply these measurements to individual components outside of the system testbed, and to be able to apply them to the end-to-end system, individual movable test stations are created. Six test stations are part of the ASC Laboratory RF testing facility, and each uses its own, or shares the use of a desktop PC controller.

The most accurate gain and phase measurements are performed using an automatic network analyzer (ANA) test station. The ANA consists of a self contained analyzer module, interfaced with test signal sources and test sets which cover several frequency ranges. The analyzer controls all instrumentation, and conducts calibration and measurement sequences, printing or plotting results through a graphics interface. An external desktop computer/controller is used for measurement sequences for specialized applications.

The noise figure test station consists of a noise figure meter in conjunction with test signal sources and noise sources, under control of a PC controller. Each component or subsystem requires a unique noise figure measurement configuration. To accommodate all possible types of measurements, a control program developed at NASA Lewis helps the user to properly configure the required instrumentation and then executes the calibration and measurement sequences, sending results to a printer or plotter.

Group delay measurements can often be obtained using the ANA test station. In many cases, however, especially for frequency conversion devices, the ANA cannot be applied. The group delay test station uses a vector voltmeter to measure the phase shift of a signal envelope modulated onto a CW carrier to enable this test. A PC controls the vector voltmeter and signal and modulation sources, and NASA Lewis developed software assists the user in properly configuring the test. The controller executes calibration and measurement sequences, and printing or plotting of results.

System or component non-linearity tests are performed with the non-linearity test station, a combination of power meters and spectrum analyzer under control of a PC controller. As with the noise figure and group delay measurements, specialized software has been developed at NASA Lewis to help configure individual tests and perform calibration and measurement routines, and prints or plots the results.

The phase noise test station consists of a dynamic signal analyzer, phase noise interface, carrier noise test set, and low noise reference signal generator, interfaced to a PC controller. Manufacturer supplied software executes calibration and measurement sequences and produces printed or plotted results. The test station can measure phase noise of sources up to 60 GHz. Phase noise measurements at remote locations can be performed with a portable spectrum analyzer, although with less accuracy.

Frequency stability measurements require a test station consisting of a highly accurately frequency reference, derived from a Loran-C receiver, together with power, current, and voltage meters. A PC controller performs periodic measurements of all parameters associated with the signal source under test. The control program measures frequency as a function of time or temperature. A thermal chamber can be controlled by the program to vary the temperature of the device under test. The frequency and length of the measurement can be varied over a wide range. The program calculates maximum deviations of all measured parameters, and deviations over selectable time increments such as hour, day, or 10-day periods.

Space Communication System Simulator and Testbed

The ASC Laboratory's main feature is the Satellite System Simulator and Testbed. The System Testbed, described by Figure 1, allows testing of individual components or subsystems within a system environment. End-to-end communications link testing using RF and modulated signals, functional testing of satellite system and network performance, system-level experimentation, and demonstration of space communications applications, are all accomplished using the System Testbed.

The satellite transponder includes an intermediate frequency (IF) matrix switch which can be connected with satellite receivers and transponders of any desired frequency band. Three ground terminals offer a Lewis-developed user simulation [Ref. 1] to allow the system to be stimulated in a realistic way. The ground terminals offer interfaces for real-world data (digital, video, voice, etc.), or can generate pseudo-noise encoded data for accurate measurement of BER. Under control of the Experiment Control and Monitor Computer (EC&M), BER is automatically measured as a function of E_b/N_0 [Ref. 2]. The EC&M controls frequency and power measurement at test points throughout the testbed, stimulates the ground terminals in a number of transmit and receive combinations, and adds simulated link impairments to the system (such as rain attenuation or satellite range variation). These functions allow complex experiment scenarios to be executed, while system parameters and ground terminal performance are monitored.

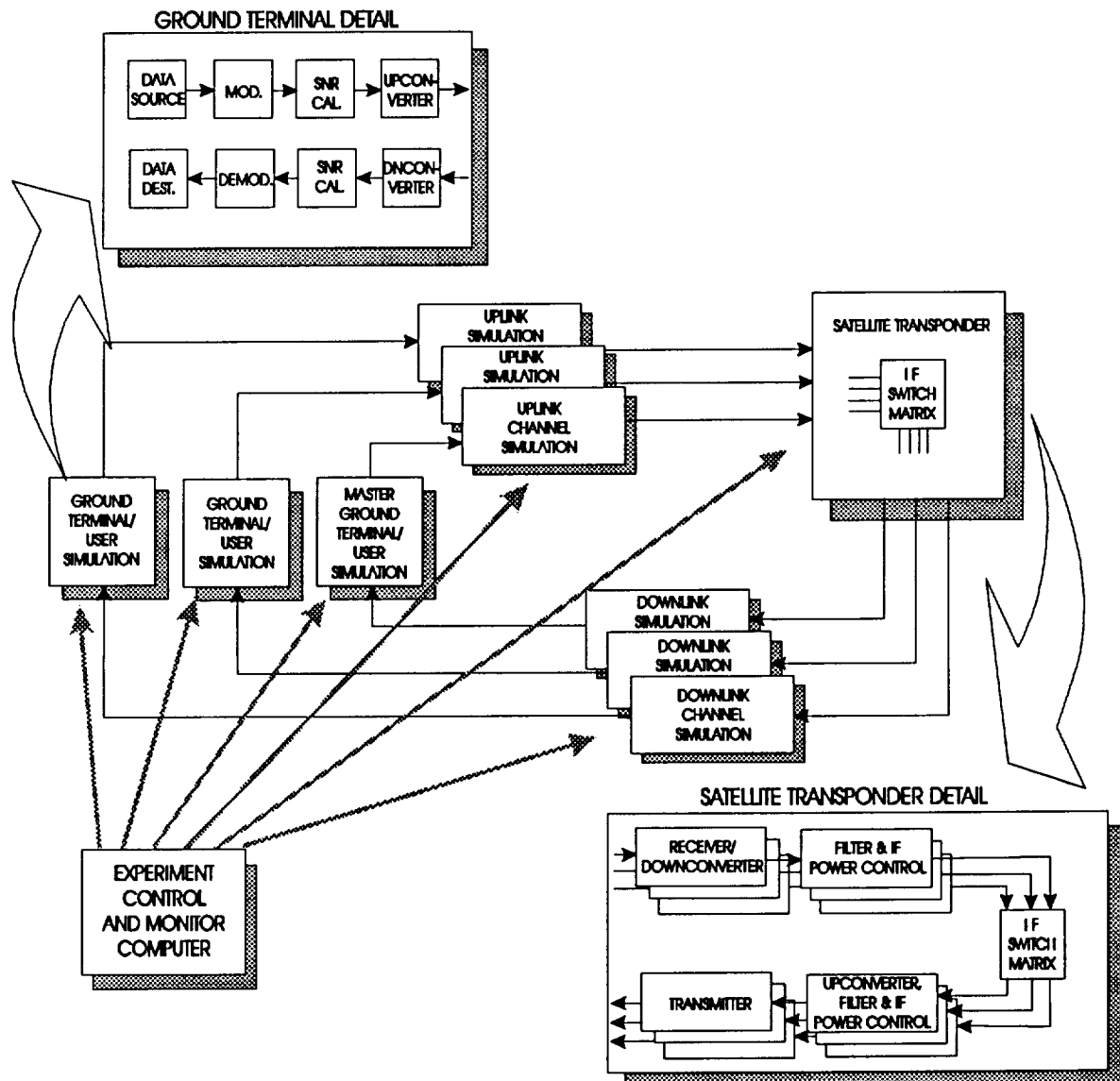


Figure 1 - Space Communications System Simulator and Testbed

The testbed contains input and output ports to which can be connected any of the RF test stations described previously. Individual components or subsystems can be inserted into the testbed, either at a point where operating frequencies and power levels properly match, or in place of an existing component. In addition to testing the RF characteristics of the system with the component or subsystem under test included, it is often desirable to observe the end-to-end system BER performance. This can indicate the degree to which the component or subsystem actually affects the communication system's integrity.

The input and output ports also allow measurement of system performance with interfering signals or adjacent channel signals added. The link simulation allows the observance of system or network (as simulated with a number of ground terminals) performance in terms of network efficiency, system synchronization, ground terminal network connection time, or BER variation, as satellite range, rain attenuation, or interference modify the uplink or downlink characteristic. Unique hardware simulations of rain attenuation and satellite range variation have been developed for the testbed [Refs. 3,4].

Space Link Testbed

The ACTS, NASA's experimental satellite, is currently available to allow Ka-band experiments with a real earth-space-earth link using a geosynchronous satellite. In addition, commercial Ku-band satellites can be accessed whenever the laboratory testbed is inadequate. The advantages of a real space link include the existence of natural atmospheric and weather conditions, the satellite range and associated time delay, and the ability to access remote experimenters who are within the range of the satellite. The disadvantage is the inability to carefully control some experimental parameters.

The ASC Lab has developed two Ka-band ground terminals, capable of high and low data rate transmissions, compatible with the ACTS. In addition, a Ku-band terminal is available for access to Ku-band satellites. The two Ka-band ground terminals, known as INTEX (Interference Experiment Terminal) and LET (Link Evaluation Terminal), allow complete end-to-end experiments to be performed at NASA Lewis, and also allow experimenting with any remote location within the Western Hemisphere which has a compatible terminal. The Ku-band terminal offers a loopback capability locally, and also can connect with remote experimenters within the view of the Ku-band satellite being used.

The Ka-band terminals are compatible with and interconnected with the ASC Laboratory's System Testbed, using the EC&M. A number of in-house designed experiments and experiments with outside organizations are underway using the ASC Lab's Space Link Testbed.

Computer Systems

There are four main computer systems involved in the operation of the ASC Laboratory. The computer systems interconnect the ASC Lab testbeds as shown in Figure 2.

The EC&M workstation computer controls and monitors the System Testbed, which involves obtaining and storing data as well as controlling IEEE 488 and RS-232 devices in real-time. For example, the programmable attenuators which vary signal power levels to allow BER measurement are controlled from the EC&M by an IEEE 488 interface. Readings from power meters are also sent via IEEE488 to the

EC&M computer. The satellite ground terminals and the data generators/checkers (see Figure 1) are commanded via RS-232 connections. Bit error rate figures are calculated from the data received from the data checkers.

The Master Control Ground Terminal (MCT) is used when the testbed is configured for a network simulation involving three ground terminals (simulated to be in remote geographic locations) and up to nine network users. The MCT computer is a 68000 based microprocessor used to acknowledge other ground terminals in the system and receive network access requests from network users. The MCT microprocessor receives the orderwires through the same communications path used for data transmission, organizes requests for connection to the network (i.e. discards invalid and duplicate requests) and sends them to the Network Control Computer (NCC). The NCC deciphers the orderwires and informs the MCT of the required action. The MCT notifies the users whether their requests were accepted or denied.

The Digital Routing Processor (DRP) is a satellite based computer/controller that receives commands from the NCC and controls several satellite components. The DRP controls an attenuator used to protect the downlink transmitter against input overload, the power processing unit which adjusts the transmitter power to one of three levels, and the matrix switch crosspoints on the IF matrix switch. A minicomputer serves as the NCC. The NCC is interfaced to the MCT computer and the DRP in the system testbed, and is primarily used for system and network level simulations.

The EC&M computer connects, through fiber optic and coaxial lines, the System Testbed with the Space Link Testbed, as shown in Figure 2. The two Ka-band experiment terminals, INTEX and LET, are in different locations from the System Testbed. Through the EC&M, both ground terminals can be controlled, configured, and monitored from a single location, using EC&M software modules.

APPLICATIONS

Several examples will serve to illustrate applications of the ASC Laboratory facilities, in the area of component evaluation, system level testing and experimentation, and applications demonstration.

NASA sponsors the development of proof-of-concept hardware for ground and space applications. A solid-state power amplifier using IMPATT diodes, developed for Ka-band ground terminal application, was tested for all relevant RF parameters using the ASC Lab RF testing facilities. Of more practical importance was the amplifier's ability to transmit high rate digital data without significant degradation. For this purpose, the System Testbed was used; the amplifier was placed in the uplink signal path, in the place in the system where the uplink transmitter would normally reside. End-to-end BER measurements indicated the degradation to the BER of the system caused by the amplifier [Ref. 5].

Satellite receivers at 30 GHz were developed using five different designs. Using the ASC Lab RF testing facilities, each of the five receivers were tested for RF performance. Then each was tested in the Space Communications System Simulator and Testbed, where the effect on the BER performance of the system could be compared directly. The results showed a significant variation in performance for the five receiver designs [Ref. 6].

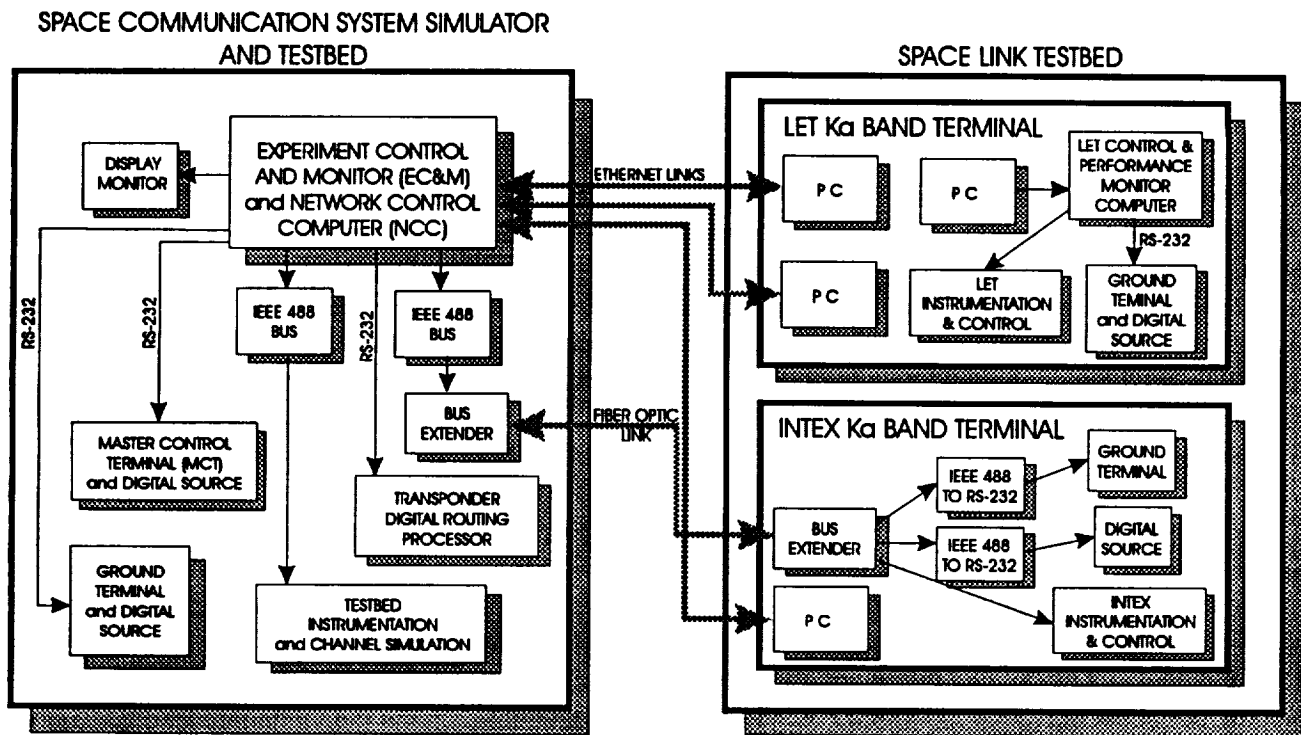


Figure 2 - NASA Lewis's Advanced Space Communications Laboratory Computer Systems and Facility Interconnections

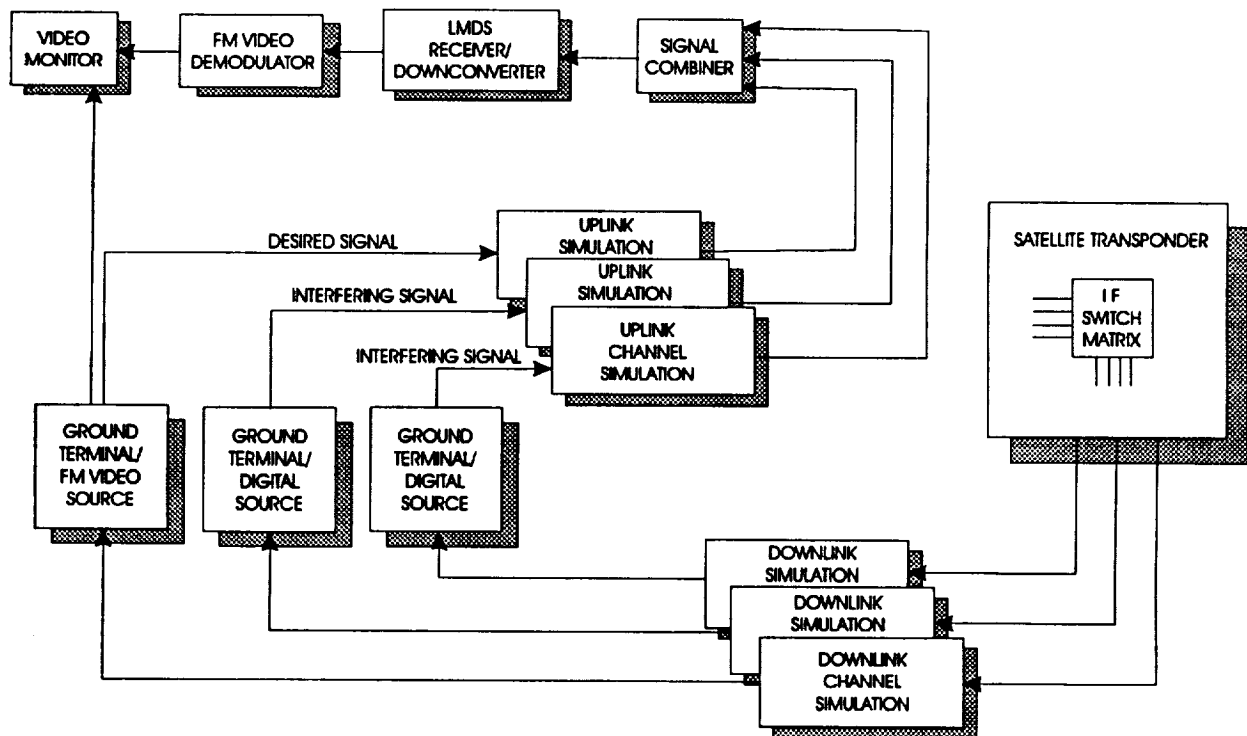


Figure 3 - Space Communications System Simulator and Testbed modified for LMDS/Satellite Uplink Interference Experiment

Satellite system designers were interested in the degree to which system amplitude variations, (that is, variation of signal gain with frequency) would affect the BER of a high data rate minimum-shift-keyed (MSK) modulated signal. Using the ASC Lab facilities and an adjustable amplitude equalizer, various amplitude profiles was simulated, and the BER degradations associated with different types and degrees of amplitude variations were measured. Of particular interest was the interrelationship with the non-linearity of the satellite transponder. Using power sensors located in the testbed, the drive level of the satellite transmitter could be varied to produce different degrees of non-linearity. The effect on the system BER performance of a wide range of amplitude profiles was measured [Refs. 7,8].

The System Testbed was modified, as shown in Figure 3, to accommodate a series of experiments designed to test the effects of high power satellite uplink transmission on terrestrial "wireless cable" systems which have been proposed for the same frequencies. Television distribution systems called local multipoint distribution service (LMDS), as well as satellite system manufacturers, worked with NASA Lewis to perform measurements to determine if the two services could coexist.

The Space Link Testbed is currently in use for a number of technology experiments and application demonstrations. A series of experiments will determine the effect of interference on link BER, and the ability of multiple signals to be transmitted and received, by using one Ka-band ground terminal in a loopback mode with the second ground terminal transmitting an interfering signal. High definition television signal transmission will be tested with an experimenter in Florida receiving transmissions through ACTS from the Lewis INTEX ground terminals in Cleveland. Compression techniques for regular and high definition video for satellite transmission will be assessed. Image compression and satellite transmission of mammography images, for application to remote rural areas, will be first tested using the Space Communication System Simulator and Testbed, and later using the Space Link Testbed in cooperation with several universities and hospitals in the Eastern United States.

CONCLUSION

The facility for the evaluation of space communications and related systems at the NASA Lewis Research Center has been described. The facility consists of RF test stations, a laboratory Space Communication System Simulator and Testbed, and a Space Link Testbed using operational satellites and ground terminals, is collectively known as the Advanced Space Communications Laboratory. The basic design of the facilities, and their capability to perform a variety of important tests and experiments on components, subsystems, systems, and networks for space communications and related systems has been described. Several examples were given to illustrate the effectiveness of the ASC Lab in meeting the requirements of space communications technology evaluation.

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